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RTNS-II Utilization Plan

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FOREWARD

The Rotating Target Neutron Source-II (RTNS-II), currently nearing completion at Lawrence Livermore Laboratory, will be the world's most intense source of 14 MeV neutrons. Sponsored by the Office of Fusion Energy of the Department of Energy, this facility is dedicated to the research, development, and testing of materials for use in fusion reactors. It will be the only such facility until the still more intense Fusion Materials Irradiation Test Facility (FMIT) is completed in 1983.

To aid in making effective use of the RTNS-II, the Hanford Engineering Development Laboratory was requested to develop a plan for its utilization. This has been done within the framework of recently completed Program Plans which cover four research areas: Alloy Development for Irradiation Performance (ADIP), Damage Analysis for Fundamental Studies (DAFS), Plasma-Materials Interaction (PMI), and Special Purpose Materials (SPM). Because the RTNS-II is limited to low-to-medium fluences and has a small test volume, its greatest application is, at least initially, in the DAFS area. Hence this Plan has much the character of a supplement to the DAFS Program Plan.

This Plan is written in general terms with the emphasis on goals. The details of implementation are left to the individual laboratory programs with coordination by the Task Groups. In this connection, an Experimenters Guide has been prepared by the Lawrence Livermore Laboratory.

This plan was prepared at HEDL by R. W. Powell with the support of D. G. Doran, J. J. Holmes and H. H. Yoshikawa. The Materials and Radiation

Effects Branch of the Office of Fusion Energy gratefully acknowledges their efforts, and the cooperation of many individuals at other laboratories, in preparing this Plan.

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I. SUMMARY

The Rotating Target Neutron Source-II (RTNS-II), currently under construction at Lawrence Livermore Laboratory (LLL), is expected to be operating at full power by March 1979. Built by the Office of Fusion Energy (OFE) for the study of radiation effects in materials, it will be the highest flux source of D-T (14 MeV) neutrons in the world. Some characteristics of the facility are given in Appendix I.

This plan describes a general program for the effective utilization of this resource by the fusion materials community. Because its flux is low relative to levels expected in commercial fusion reactors, the RTNS-II is not expected to produce data of direct engineering significance (with some exceptions). Rather, it will be used chiefly to aid in the development of models of high energy neutron effects. Such models are needed in projecting engineering data obtained in high flux fission reactors to the fusion environment. Fission reactors, because of their relatively soft neutron spectra, cannot produce the high ratio of transmutations to displacements (except in an important special case) or the high energy recoil atoms appropriate to fusion reactors utilizing the D-T reaction.

The Office of Fusion Energy has established four Task Groups to coordinate the development of fusion materials. Each Task Group has prepared a Program Plan. Only that of the Task Group on Damage Analysis and Fundamental Studies (DAFS) includes a significant role for low flux high energy neutron sources such as RTNS-II. Therefore this Plan for RTNS-II has been prepared within the framework of the DAFS Program Plan. In particular, the research areas in both plans are environmental characterization, damage production, and microstructure evolution and mechanical behavior.

This plan was prepared with the assistance of many people. It was preceded by a survey in which potential users of the facility were asked to describe briefly the experiments they would like to do. Their responses are

summarized in Appendix II. These responses, along with the DAFS Program Plan, provided the context within which this plan was written.

The Strategy section of the plan includes a brief description of the status of high energy neutron experiments. Most of these have been of an exploratory nature with a minimum of analysis. (A strong segment was concerned with neutron sputtering, but this problem is now assigned a low priority). The performance of systematic experiments to test and calibrate damage production models is the initial thrust of the plan. It is suggested that significant experiments may also be possible on the effects of helium and hydrogen production, but this must be demonstrated because maximum attainable concentrations are only a few appm. Similarly, experiments on the evolution of the damage microstructure and on changes in mechanical behavior will require maximum possible fluences. Such experiments may start with simple materials, which are generally more radiation sensitive than engineering materials, but many effects of interest will require the use of more complex materials.

Priorities have been assigned; the highest are reserved for primary damage state measurements; effects of helium and primary recoil spectrum on microstructure and mechanical behavior; and RTNS-II environmental characterization, including measurements of helium production rates.

Twelve task descriptions, each containing several subtasks, are given for the period 1979-1983. They are, in effect, expansions of task descriptions in the DAFS Program Plan, and the relationships between the two plans are shown explicitly.

II. INTRODUCTION

The purpose of this plan is to formulate a general program for the effective utilization of the RTNS-II by the fusion materials community. Because of its relatively low flux, the RTNS-II is precluded, with few exceptions, from producing data of direct engineering significance. It follows that RTNS-II utilization must be discussed within the context of the overall strategy for producing technological data; hence, the scope of this plan extends beyond the use of RTNS-II.

A comprehensive program has been extablished by the Materials and Radiation Effects Branch of the OFE to assess materials problems in Magnetic Fusion Reactors (MFRs) and to develop new materials and new applications of existing materials as needed. To coordinate the program, four task groups have been organized:

1) Alloy Development for Irradiation Performance (ADIP),
2) Damage Analysis and Fundamental Studies (DAFS),
3) Plasma-Materials Interactions (PMI), and
4) Special Purpose Materials (SPM).

The ADIP Task Group is concerned with development of improved materials for first wall application; DAFS is concerned with the interpretation of radiation effects data obtained in various test facilities and projecting them to MFR environments; PMI is concerned with the interaction of the first wall with the plasma, hence surface effects; and SPM covers all materials other than the first wall. Each task group has prepared a general program plan. Only the DAFS plan includes a significant role for low flux, high energy neutron fields; hence, this RTNS-II utilization plan was prepared within the framework of an ongoing DAFS program.

Much of the current effort in the fusion materials program is centered on the first wall, where the environment will be the most severe and the most atypical of current experience. Prime threats to its mechanical integrity are the high energy (14 MeV) neutrons from the D-T reaction and possible cyclic loading at elevated temperatures. The higher neutron energies in the fusion environment will produce more energetic displaced atoms and a greater abundance of nuclear reactions that produce helium, hydrogen and other transmutation products than is the case in fission reactor irradiations.

No test facilities provide high fluxes of high energy neutrons in the large experimental volumes needed for alloy development research. Only fission reactors have the large test volumes required to produce engineering data. The DAFS Task Group is to provide guidance in designing and interpreting fission reactor irradiations and in projecting the results to MFRs.

High energy neutron facilities provide the necessary link between the two neutron irradiation environments. The characteristics of these facilities are listed in Table 1; they differ in neutron flux, neutron energy spectrum, experimental volume, and availability. The combination of these factors dictates the best utilization of each facility.

The highest flux device available in the near future is the RTNS-II. It is also the only available device that was designed to operate as a materials irradiation facility on a continuous basis. Hence higher fluences can be obtained in RTNS-II than in other facilities. Even so, the maximum exposure likely to be achieved in this device is about three orders of magnitude below the goal exposure of the alloy development program. Thus, it should be expected that the RTNS-II and cyclotron sources will be used chiefly as tools to understand and model the nature of high energy neutron damage.

Table 1

High Energy Neutron Facilities

Facility Name	Neutron Reaction	Approx Peak Flux($n/cm^2 \cdot s$)	Corresponding Displacement Rate in AISI 316 (dpa/s)	Weekly Displacements in AISI 316 (dpa)	Availability
Dedicated Materials Facilities					
Rotating Target Neutron Source - II (RTNS-II)	T(d,n)	1×10^{13}	3×10^{-8}	0.008(a)	1979
Fusion Materials Irradiation Test Facility (FMIT)	Li(d,n)	1×10^{15}	2×10^{-6}	1.0(b)	1983
Multipurpose Facilities					
Rotating Target Neutron Source-I (RTNS-I)	T(d,n)	2×10^{12}	6×10^{-9}	0.002(a)	(d)
University of California-Davis Cyclotron (variable energy)	Be(d,n)	5×10^{12}	1×10^{-8}	0.007(c)	Currently
Oak Ridge Isochronous Cyclotron (ORIC) (variable energy)	Be(d,n)	2×10^{12}	4×10^{-9}	0.003(c)	(d)

(a) Assumes operation for 80 hours per week.

(b) Assumes operation for 24 hours per day, 7 days per week with an 80% plant factor.

(c) Assumes operation at 35 MeV for 24 hours per day, 7 days per week. Much longer irradiations than one week are not practical, so this weekly fluence is near the maximum attainable.

(d) No longer available for materials studies

The low damage rates in RTNS-II and cyclotron sources relative to that expected in a fusion reactor means that possible rate effects must be considered in applying data obtained in these facilities to the fusion environment.

None of the facilities accurately mimics a first wall spectrum. The utility of the RTNS-II facility is enhanced for some purposes, in fact, by the nearly mono-energetic character of its spectrum.

The FMIT facility is a medium-to-high flux device planned for operation in 1983. The broad neutron energy spectrum produced by the Li(d,n) stripping reaction employed in this device is peaked near 14 MeV for 35 MeV deuterons; a very low intensity tail extends beyond 40 MeV. Although MFRs will not have neutron energies above 15 MeV, the ratio of helium to displacement production in the Li(d,n) energy spectrum is expected to be close to that of an MFR first wall spectrum. The primary recoil spectrum has a low intensity high energy tail, but otherwise is more similar to that expected in an MFR first wall than the primary recoil spectrum produced by 14 MeV neutrons.

The other facilities available for high energy neutron studies universally employ the Be(d,n) reaction to produce neutrons, e.g., the UC-Davis device which provides a flux somewhat lower than the RTNS-II. The spectrum is similar to that from the Li(d,n) reaction. Careful experiments utilizing a Be(d,n) source and the RTNS-II will elucidate the effect of neutrons with energies greater than 14 MeV.

It has been pointed out that low flux, high energy facilities are useful primarily for fundamental studies. Nevertheless, some MFR components may be subjected to such low fluences of high energy neutrons that goal exposures may be achieved in RTNS-II. Examples of such materials are superconducting magnets and organic insulators.

III. STRATEGY

A. Introduction

The overriding damage analysis objective is the development and validation of correlation procedures for projecting fission reactor data to fusion environments. Most of the problems discussed here arise in attaining that objective. For convenience of reference, the organization of this section parallels that of the DAFS Program Plan.[1] A summary of the strategy is depicted in Figure 1.

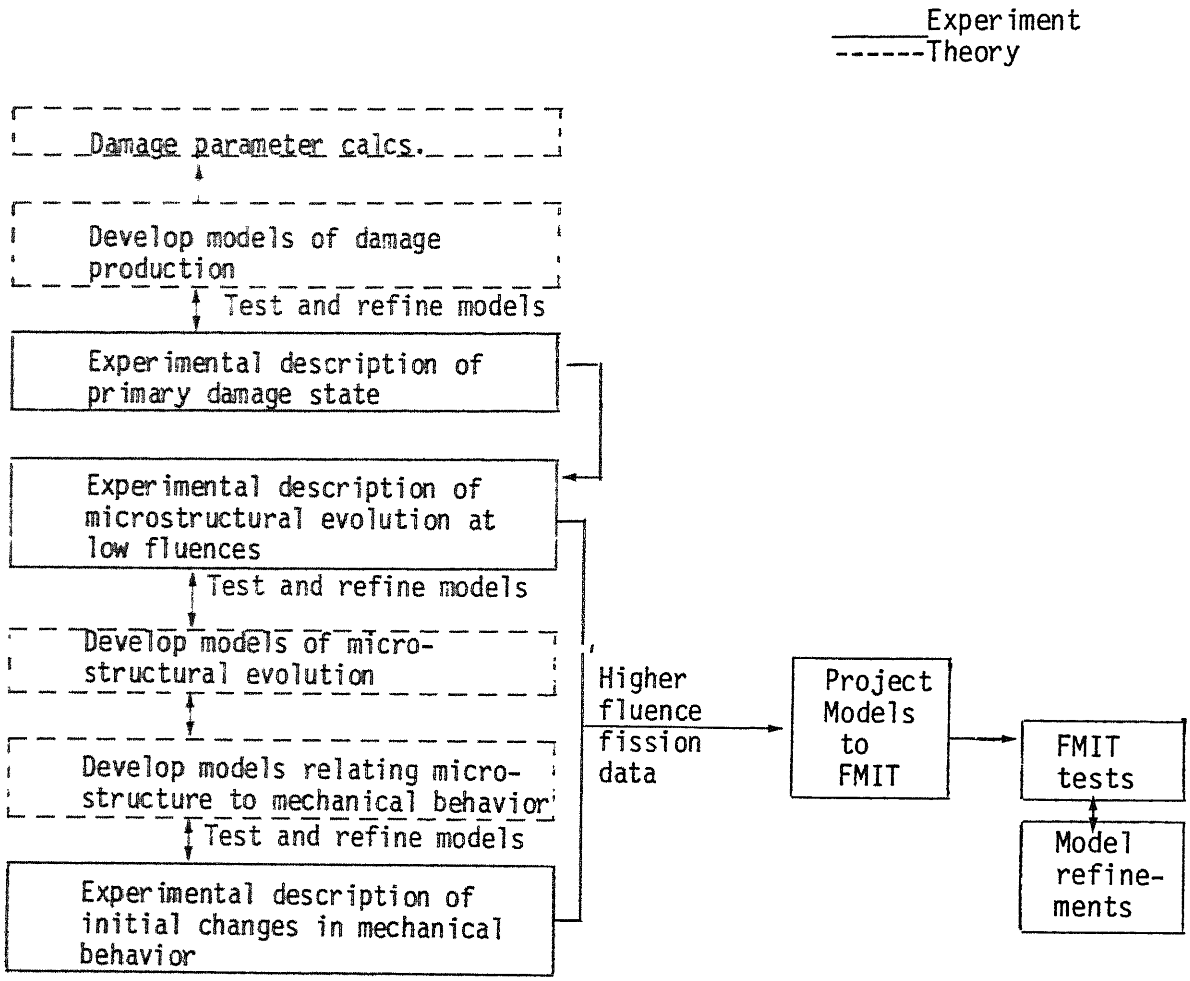
In addition, however, several engineering questions that can be directly attacked with low flux sources are also described.

B. Irradiation Environment Characterization

1. Description of the RTNS-II Flux/Fluence/Spectrum

RTNS-II will be utilized for quantitative studies of irradiation effects; hence an accurate description of the irradiation environment is essential for the application of these studies to model development and for correlation with other data.

Dosimetry for RTNS-I was adequate. Fluence uncertainties of 5-10% were obtained by measuring the rate of the Nb(n,2n) reaction; corrections for source variations were deduced from an on-line proton recoil spectrometer. Application of these techniques to the very similar RTNS-II will require some adaptation and demonstration. Mapping experiments at RTNS-I[2] and calculations for RTNS-II[3] have shown that positional dosimetry is essential, i.e., in-situ dosimetry must be sufficient to define corrections for misalignment of specimen and source.



Supporting Activities

- Perform comparative low fluence fission reactor irradiations
- Develop and assess techniques for dosimetry and for defect detection
- Characterize irradiation environemnts: RTNS-II, Be(d,n), Li(d,n)

FIGURE 1. Relationship of High Energy Neutron Experiments to DAFS Program

2. Development of Improved Dosimetry Techniques

Long-term irradiations require long-lived or stable product monitors to determine the fluence accurately. The helium accumulation technique and the radiometric method utilizing long-lived products should be pursued (Nb monitors have a ten-day half-life). The nearly mono-energetic nature of RTNS-II makes it ideal as a reference field for the validation and calibration of cross sections used in passive and active dosimetry. The main goal is more precise dosimetry for long RTNS-II irradiations although the results will also apply to Be(d,n) and Li(d,n) facilities.

The rapid spatial variation in neutron flux at RTNS-II (and other high energy neutron facilities) requires dosimeters capable of high spatial resolution. Currently used passive monitors are adequate but new techniques should be explored in an effort to maximize the information gained and minimize the cost.

3. Accurate Determination of Helium and Hydrogen Generation Rates

Helium is expected to play a major role in the behavior of first wall materials; hence accurate predictions and determinations of helium generation rates in various materials are necessary. To aid in this, it is important that the determination of the energy dependence of total helium production cross sections be vigorously pursued.(5)

The problem of helium generation rates is not restricted to bulk rates for candidate alloys. It is important to know helium generation cross sections for certain elements that may segregate to various internal sinks, so that local helium generation rates can be determined. An example is carbon which has a large helium production cross section for 14 MeV neutrons(4) and also segregates to grain boundaries.

Gas mass spectrometry has been used to determine helium concentrations at levels below 1 appb in very small specimens.[6] Thus, direct determinations can be made for RTNS-II irradiations where helium concentrations on the order of a few hundred appb per week will be produced in AISI 316. Hydrogen effects on irradiated material behavior have not yet been assessed. Planned scoping experiments may indicate the need for hydrogen generation measurements for various elements in RTNS-II and Be(d,n) fields. Particle recoil and radiometric techniques (when a suitable reaction product exists) should be applied.

4. Assessment of Flux/Fluence/Spectrum Characteristics of Be(d,n) and Li(d,n) Facilities

There is considerable interest at this time in using Be(d,n) fields to complement radiation effects studies made at RTNS-II by providing a different high energy neutron spectrum. There is also interest in using such fields for pre-FMIT studies, particularly the development of passive, active, and calculational dosimetry techniques.[7] The latter application may soon predominate, unless unexpected differences surface between effects seen with 14 MeV neutrons and Be(d,n) neutrons.

Characterization of these fields and dosimetry development should be coordinated with the corresponding activities at RTNS-II.

C. Damage Production

1. Introduction

Almost every neutron interaction produces a cascade of displaced atoms. At damage rates expected in MFRs, intra-cascade

defect interactions called "short-term annealing" occur on a time scale that is short compared to inter-cascade interactions. The primary damage state is the defect configuration which exists following short-term annealing of the cascade; it consists of defect clusters and the "free defects" which avoid clustering and annihilation and thus escape from the vicinity of the cascade. The nature of the defect clusters (including type, configuration, size and concentration) and the number and type of free defects are the critical parameters of interest. Damage production studies involve the characterization of this primary damage state.

The primary damage state, as defined, is a function of irradiation temperature. There are generally considered to be four broad temperature regimes, characterized by 1) no thermal diffusion of defects, 2) diffusion of self-interstitials but not vacancies, 3) diffusion of both types of defects, and 4) self-diffusion or vacancy cluster dissolution. Typical temperatures corresponding to these four regimes are, for metals, liquid helium (4 K), room temperature, one-third the absolute melting point and one-half the absolute melting point.

The mean cascade energy in a stainless steel first wall for current MFR designs is about 50 keV, compared with 10-20 keV in fission reactors. The accurate determination of the contribution of higher energy cascades to the primary damage state, including interactions with He, is an important first step in determining the effect of high energy neutrons on microstructure and properties. Models of displacement damage production are being developed.[8-10] Experimental data are required for their accurate development, for calibration of parameters, and for the validation of the models under new experimental conditions.

2. Experimental Determination of the Primary Damage State

Most high energy neutron studies performed to date have been of an exploratory or scoping nature, with generally minor attempts made to interpret results using available defect production models. The only correlation parameter examined seriously is the damage energy, calculated universally from the Lindhard energy partition model. (The damage energy is the fraction of deposited energy not dissipated in electron excitation, hence available to displace atoms). The total number of displacements, assumed to be proportional to the damage energy, has also been used in estimating the "defect production efficiency" per neutron.

Some studies were conducted at RTNS-I at cryogenic temperatures and the results compared with fission reactor irradiation. The initial damage rate, as indicated by changes in electrical resistivity was found to scale with the damage energy ratio for the two irradiation environments.(11,12) One of the investigations found that the 14 MeV neutrons were a factor of 2-3 less effective in producing defects than would be predicted by converting damage energy to displacements using a modified Kinchin-Pease model.(12) An isochronal annealing study(13) of the resistivity recovery following low temperature neutron irradiation indicated that the defect retention in heavier elements (Pt compared to Cu) is greater for high energy neutrons relative to fission neutrons than the damage energy ratio would predict. Other low temperature irradiations with fission and high energy neutrons have shown that various superconductor properties do not scale with the damage energy.(14,15)

Most RTNS-I irradiations were performed at room temperature. Although there is some conflicting evidence, TEM investigations of intermediate atomic weight elements indicate that the nature of the radiation damage in fission and 14 MeV neutron spectra is qualitatively similar. For example, the number of defects retained in detectable clusters at low

fluence scales with the damage energy for Cu and Nb.[16-18] The same scaling does not hold for Au, however.[19] Damage energy scaling has been found to be inaccurate for other properties including tensile yield strength of some pure metals,[20,21] lattice parameter increase,[22] and enhanced diffusion.[23,24]

A few investigations have been performed at elevated temperatures but, since microstructural evolution becomes increasingly important at these temperatures, the results will be discussed in the Microstructure Evolution Section.

In addition to RTNS-I irradiations, a few experiments have been carried out in Be(d,n) spectra. Damage energy scaling between these two environments has been found to be adequate. Differences in the apparent primary damage state produced by 14 MeV and broad spectrum Be(40 MeV d,n) neutrons were observed in one comparative investigation at room temperature.[19] The former produced subcascade formation (defined in that work as two or more vacancy clusters within 10 nm of one another) in Cu but the latter did not.

Material variables, especially atomic weight and impurity content are important in studies of the primary damage state. A significant difference has been observed in the <u>apparent</u> primary damage state produced in a pure metal compared to an alloy.[25] Only 0.1% of the calculated number of defects generated during a room temperature, 14 MeV neutron irradiation of pure 316 stainless steel (Fe-Ni-Cr-Mo) were retained. A comparable irradiation of Cu yielded a defect retention of about 6%. The reason for this difference has not yet been determined.

It should be emphasized that postirradiation examinations of specimens irradiated at elevated temperatures (mid-temperature and above) do not yield the primary damage state. For example, in various experiments a significant fraction of the observed clusters were identified as

interstitial in character.[18-20,26] Although such clusters may be formed within a single cascade, they are more likely indicative of microstructural evolution through defect diffusion. Furthermore, the majority of apparent subcascades (multiple clusters) actually comprise both vacancy and interstitial clusters,[16,18] indicating the importance of defect diffusion on the interpretation of cascade size.

In summary, damage production studies with high energy neutrons have demonstrated differences from fission reactor neutron irradiations. The damage, as measured by various techniques, is greater for the high energy case. In some instances the difference can be accounted for by a convenient correlation parameter, the damage energy. In other instances, the damage energy under-predicts the observed difference. Scoping experiments have shown differences between pure metals and alloys (at room temperature). In few cases have detailed comparisons between experiment and theoretical models been made. Correlations at low temperatures are most directly related to damage production models, but are not directly applicable to the elevated temperature conditions of interest. Elevated temperature irradiations aimed at damage production, on the other hand, must take account of microstructural evolution to avoid erroneous characterization of the primary damage state.

Experiments at RTSN-II should be conducted in all four temperature regimes described above. In the low temperature regime, the primary damage state (at that temperature) is determined in the absence of microstructure evolution. Such experiments must be used to calibrate cascade models, since the low temperature primary damage state cannot be directly extrapolated to the high temperatures of interest. Various techniques should be utilized. Electrical resistivity measurement coupled with annealing studies, applied to specific classes of materials, provides confirmation of total defect production, free defect production, and defect trapping (potentially yielding cluster information). Fluences extending beyond past studies should be employed

to observe resistivity increase saturation and obtain information on cluster size. The study of superconductor materials adds the cluster detection techniques associated with superconductor properties.

Mid-temperature studies should continue to be important, partly because of the greater availability of detection techniques for near room temperature studies. The most valuable technique will continue to be transmission electron microscopy (TEM) since more cluster information (concentration, distribution, size, shape and type) is obtained than with any other detection technique. Mid-temperature studies require that the type of cluster be determined since cluster type has important implications on the primary damage state description. Other techniques need to be employed to provide information on clusters smaller than the TEM resolution limit and on individual defects. X-ray diffuse scattering, in the former category, has the advantage of being more rapid than TEM and of integrating over a bulk specimen. Selected field ion microscopy (FIM) studies should be performed to provide cluster data on an atomic scale. Tensile property studies should be performed but the relationship between yield strength increase and cluster characteristics must be determined in order for these studies to yield primary damage information. Resistivity (including annealing) and radiation enhanced diffusion studies should be employed to assess the individual defects.

Increasing emphasis should be placed on elevated temperature damage production irradiations because of the importance of determining the primary damage state at temperatures of interest to MFR operation. This is emphasized by the influence of the primary damage state, especially cascade cluster type and shape, on microstructure evolution. The difficulty of separating the primary damage state from microstructure evolution necessitates the use of new experimental techniques and will be discussed in the next section.

Studies of the primary damage state in pure metals should continue and be extended to simple and complex alloys. The differences in the primary damage state between pure metals and alloys must be determined to aid in model development.

While a primary objective is the characterization of damage production by 14 MeV neutrons, an important secondary objective is to understand how it differs from that caused by fission neutrons. In addition, studies should be performed to assess possible differences between the effects of 14 MeV neutrons and broad spectrum Be(d,n) neutrons peaking near 14 MeV.

Experimental programs aimed at assessing the primary damage state must be closely tied to theory since, in general, the primary damage state cannot be experimentally separated from effects of microstructure evolution. This integration of experiment and theory (both cascade development and microstructure evolution theories) should be a major aspect of damage production studies conducted at RTNS-II.

3. Development of New Experimental Techniques for Damage Production Studies

Damage production studies are hampered by two important factors. Firstly, the primary damage state consists of very small entities: defect clusters which may range in size down to a few angstroms, and individual atomic defects. To detect and quantify such small entities requires a variety of experimental techniques, since no single one is capable of measuring all aspects of the damage state. Secondly, the relationship between what is inferred from these measurements and the true primary damage state at the temperature of interest can be complicated by the process of defect migration.

Various detection techniques have been used in high energy neutron studies and others appear to have promise. TEM examination,[16-20,25-28] X-ray diffuse scattering,[16,25] resistivity (both initial increase and recovery),[11-13,22] yield strength increase,[20,21] lattice parameter increase,[22] superconductor property change,[14,15] and radiation enhanced diffusion[23,24] have all been used. Further work should be performed to assess the application of small angle scattering (both X-ray and neutron) and positron annihilation to the detection of submicroscopic entities. High resolution transmission electron microscope techniques such as fringe imaging should be explored. Special TEM techniques for detecting lattice defects in ordered alloys or alloys with ordered precipitates require investigation. Past studies have used electrical resistivity of ordered alloys to study point defects through radiation enhanced diffusion (producing order) but it should also apply to cluster size studies through the resistivity increase. The feasibility should be determined of performing low temperature TEM examination following low temperature irradiation (with no intermediate warm-up) to directly determine the nature of low temperature cascades. An early effort in this task should be a detailed review of all possible detection techniques.

Experiment design to minimize the effects of microstructure evolution on the primary damage state is also important. Low fluence data combined with detailed cluster-type identification are likely to be adequate for mid-temperature irradiations. High temperature irradiations pose a more serious problem. Again, low fluence irradiations should be employed for damage production studies to reduce interaction of defects from one cascade with the structure of another cascade. Scoping studies should be performed to assess the feasibility and effectiveness of using various pre-irradiation microstructures to further isolate cascades and provide a basis for measuring the free defect production.

D. Damage Microstructure Evolution

RTNS-II will be used in damage microstructure evolution studies to provide low fluence correlation data for microstructure evolution model development. High fluence calibration of the models will be performed in fission reactors and at FMIT. FMIT will have a limited test volume with high demands on its use and fission reactor irradiations require long lead times before results are available. Therefore, early development of models is needed to aid experiment planning and the analysis of experimental results. As in the damage production studies, the process will be iterative since improved models will lead to improved experiments.

The four tasks in the area of damage microstructure evolution requiring RTNS-II experiments are 1) the effect of the primary recoil spectrum, 2) the effect of helium, 3) the effect of hydrogen and 4) relating high and low exposure microstructures.

1. The Effect of the Primary Recoil Spectrum on Microstructure Evolution

Comparative irradiations in RTNS-II and other environments (fission reactors, Be(d,n) facilities, etc.) will provide data on the effect of the primary recoil spectrum on microstructure evolution. Two problems in data interpretation are 1) eliminating or accounting for effects due to other differences in the irradiations (e.g., helium production and damage rate), and 2) adequately detecting the microstructure.

Room temperature investigations of changes in yield stress with fission and high energy neutrons have shown that the damage energy is an inadequate scaling parameter.[20,21] Even though the fluences were very low, this spectrum effect must be interpreted in terms of

microstructure evolution as well as damage production. At the higher fluences possible with RTNS-II there is increased likelihood that differences other than in primary recoil spectrum must be considered in interpreting spectral effects. Increased experimentation at higher temperatures will accentuate effects of microstructure evolution. Separating out a primary recoil spectrum dependence will require strong appeal to models and close coordination of the various tasks aimed at determining the effects of other variables.

The problem of detecting microstructural features produced during elevated temperature irradiation at RTNS-II will depend on the material. Dislocation loop growth is classically the first indication of microstructure evolution in fission reactor irradiated materials, while voids are not detectable until higher fluences. One fission reactor irradiation produced observable voids in nickel at a fluence of only 4×10^{17} n/cm^2 (E>1 MeV)[(29)] while other low fluence investigations of nickel indicated voids after 1×10^{18} n/cm^2 (E>0.1 MeV)[(30)] and 5×10^{19} n/cm^2 (E>1 MeV).[(31)] In contrast, fast reactor fluences greater than 10^{21} n/cm^2 (E>0.1 MeV) are required to produce observable voids in stainless steel.[(32)] Considering the greater effectiveness of 14 MeV neutrons in producing displacements and assuming total displacements is a critical parameter, the corresponding RTNS-II fluences for void formation would be approximately 2×10^{17} n/cm^2 for nickel and 2×10^{20} n/cm^2 for stainless steel. Initial studies should emphasize pure metals and simple alloys while including scoping experiments to identify appropriate complex materials for later investigations.

As with the damage production studies, a number of techniques should be applied to properly assess all aspects of the microstructure. The importance of determining cluster type (i.e., vacancy or interstitial) makes TEM examination critical to these studies. Void diameter sizes down to 1.5 nm are detectable with conventional TEM

techniques.[33] Other techniques include X-ray diffuse scattering, small angle scattering, advanced TEM techniques, positron annihilation and mechanical properties measurements. Calibration studies are still needed to correlate some of the above measurements with the microstructure.

Maximum fluence irradiations are appropriate for these investigations to provide model calibration over the widest fluence range possible.

2. The Effect of Helium on Microstructure Evolution

One of the prime concerns in first wall alloy development studies is the relatively high internal helium generation rates which will be produced in first wall materials. Fast Breeder Reactor studies have shown the importance of helium in high temperature embrittlement, void formation and dislocation loop formation. These effects will be magnified for fusion first wall materials where helium generation per displacement will be more than two orders of magnitude higher than for these past fast reactor (EBR-II) studies.

It is anticipated that helium effects on the microstructure will be observable with RTNS-II irradiations. Roughly 1 appm of helium will be produced in AISI 316[34] after a fluence of 1×10^{19} n/cm^2. Past studies on nickel (not high energy neutron irradiated) indicated a very pronounced effect of 0.4 appm helium on the tensile ductility.[35] Ion bombardments exploring different techniques of helium injection (preinjection and simultaneous injection) have found pronounced effects of helium on the developing dislocation loop structure.[36]

Helium effects in nickel alloys can be studied in mixed-spectrum reactors because of the two-stage reaction $^{58}Ni(n,\gamma)^{59}Ni$

$(n,\alpha)^{56}Fe$ which has a high cross section in soft spectra. With spectrum tailoring in such reactors, helium-to-dpa ratios for given alloys (the generation rate is a function of nickel content) can approximate those expected for fusion reactors. Helium effects are not as easily studied in alloys without Ni since similar reactions do not exist for most other elements. Even for nickel alloys, the required buildup of ^{59}Ni means that initial fusion helium generation rates cannot be duplicated in mixed-spectrum irradiations. Furthermore, helium generation in fusion reactors may be more spatially inhomogeneous than in fission reactors due to segregation or precipitation of elements, such as carbon, which have high helium generation rates only in the fusion spectrum. The distribution of helium is important; it depends not only on the distribution of helium generation sites but also on helium mobility during irradiation, trapping and detrapping mechanisms, and helium bubble formation, migration and growth. All of these phenomena can be influenced by the primary recoil spectrum. Model development requires that the various effects be separable from one another as well as detectable.

Close coordination must be maintained with other DAFS investigations on the characteristics of helium in irradiated metals. Comparative irradiations in other facilities (fission reactors, Be(d,n), dual beam charged particle) with different He/dpa ratios are needed. Helium doping should be employed in some irradiations (as are already planned in some non-RTNS-II studies) to delineate the effects of initial helium. In addition, efforts should be made to characterize the distribution of helium following RTNS-II irradiations and what affects this distribution. High energy neutron irradiations of helium injected material will provide information on helium re-solution from bubbles due to cascades.

Maximum fluence irradiations should be performed to extend the study to increasing levels of microstructural development. However,

high fluence investigations aimed specifically at helium effects should evolve from ongoing studies. Investigation of possible displacement rate effects is needed in conjunction with helium studies since RTNS-II irradiations will be performed at lower rates than will be encountered in MFR first walls.

3. The Effects of Hydrogen on Microstructure Evolution

Hydrogen will be generated in the first wall at rates roughly three times greater than helium generation rates (for most materials).[34] This high rate of hydrogen generation (approaching 500 appm/yr in AISI 316 at $1 MW/m^2$) may influence microstructure evolution and is not simulated in mixed-spectrum fission reactor irradiations.

Very few data are available on the effects of hydrogen on microstructure evolution but various mechanisms have been postulated. They are expected to be highly material sensitive. Absorption of hydrogen at void surfaces would increase the void nucleation and growth rates by decreasing the surface energy.[37] A similar decrease in the stacking fault energy associated with dislocation loops would result in an increased loop growth rate.[38] Hydrogen combining with impurities (such as oxygen or carbon) could result in the formation of insoluble gases producing void nucleation and growth effects similar to those of helium.[37]

Limited scoping studies are appropriate for this area of investigation. The results of these scoping studies will indicate whether intensive studies should be initiated at RTNS-II.

4. Relating High and Low Exposure Microstructure

The high exposure microstructure following MFR irradiation is the quantity of interest but it cannot be obtained directly at this

time. RTNS-II will provide the low exposure microstructure produced by high energy neutrons while fission reactor irradiations will provide the high exposure microstructure produced by lower energy neutrons. Microstructure evolution models will be developed to predict the high exposure, high energy neutron induced microstructure with the guidance of these experimental data. FMIT will provide the eventual verification and calibration of these models at high fluences.

Early indications of high fluence behavior are needed to insure the proper development of these microstructure evolution models. Scoping studies should be performed where RTNS-II provides the "seed" microstructures for growth in other facilities. The relationship of these high fluence microstructures with those produced without seeding will provide information on the importance of the nucleation microstructure in determining subsequent evolution.

Maximum fluence RTNS-II irradiations should be a part of these investigations in an effort to surpass the microstructure nucleation stage and to overlap with the broad data base from EBR-II irradiations.

E. Fundamental Mechanical Behavior

The mechanical behavior of candidate materials is a major factor in determining the lifetime of a fusion reactor first wall. An understanding of the fundamental processes controlling the mechanical behavior of irradiated materials is needed to properly predict fusion environment behavior from fission reactor data. The strategy of RTNS-II utilization for fundamental mechanical behavior studies is to investigate to the extent possible, in close conjunction with microstructure evolution studies, the effect of various aspects of high energy neutron irradiation on the mechanical properties.

A critical question is what properties of what materials can be studied at the attainable fluence levels. The most promising are simple tensile properties and microhardness. The latter is especially attractive because it is essentially nondestructive, thereby permitting the accumulation of fluence data on a single specimen. A closely related question is how can specimens be designed to maximize the information gained while minimizing the specimen volume. Test and specimen design development for RTNS-II irradiations will also be applicable to FMIT studies where the demand on high flux test volume is expected to be large.

Comparative irradiations at various temperatures and irradiation facilities will be required for the development of mechanical property models. These models will serve two purposes. They will contribute to the ability to predict mechanical properties from a knowledge of the microstructure (other models will predict the microstructure from the irradiation conditions), and they will permit mechanical property measurements to be used as tools for characterization of damage production and microstructure evolution.

The areas for study are 1) the effect of the primary recoil spectrum on flow and fracture, 2) the effect of transmutant helium on flow and fracture, and 3) the effect of hydrogen on flow and fracture.

1. The Effect of the Primary Recoil Spectrum on Flow and Fracture

Both indirect and direct effects need to be considered. The primary recoil spectrum (or the resulting primary damage state) can affect microstructure evolution (preceding section) which, in turn, will affect the mechanical properties. Correlation of microstructure with mechanical properties following mid-temperature and elevated temperature RTNS-II irradiations, complemented by comparative irradiations in other facilities, should be utilized to determine such effects.

Extending the fluence dependence to the maximum possible is appropriate in order to magnify the observed effects and extend the range of microstructural correlation; however, transmutation effects may cause increased problems of interpretation at the higher fluences.

The primary recoil spectrum can directly affect mechanical properties through variations in the production of cascade clusters and free defects. Mid-temperature and low-temperature tensile property studies will assess the effectiveness of high energy neutron cascades in impeding dislocation motion. Low fluence irradiations (before significant cascade overlap) are best for these studies although some experiments should be performed to maximum fluences to check model predictions. At the lower fluences, helium and hydrogen effects should be negligible. These studies will be used as characterization tools to test and calibrate primary damage state models.

The feasibility of performing creep tests in RTNS-II should be examined. Creep studies provide information on the combined effects of the primary damage state (both clusters and free defects) and microstructure evolution. Varying fluences and temperatures should permit separation of these effects. Coordination with helium and hydrogen studies might be needed to identify the effects of these transmutation products at the higher fluences.

2. The Effect of Transmutant Helium on Flow and Fracture

Helium is known to decrease elevated temperature ductility significantly in fast reactor irradiated materials. The close tie with microstructure evolution studies is evident in this area since knowledge of the helium distribution is essential to the understanding of this effect. Other factors to be determined include the dislocation barrier strength of helium bubbles and the effect of helium on the strength of other dislocation barriers.

Helium embrittlement studies have not been performed on material irradiated with high energy neutrons, but other types of investigations indicate that such studies are feasible with RTNS-II. Under conditions of high temperature and low strain rate to promote grain boundary failure, alpha particle injected nickel (to only 0.4 appm) showed a significant decrease in tensile ductility compared to non-injected nickel.[35] Helium embrittlement has also been observed in fast reactor (EBR-II) irradiated AISI 316 at fluences as low as 5 x 10^{21} n/cm^2 (E>0.1 MeV).[39] The helium content at this fluence was not determined analytically but it is estimated to be considerably less than 1 appm. As noted previously, more than 1 appm He should be generated in AISI 316 stainless steel after a fluence of 10^{19} n/cm^2 in RTNS-II.

Studies should be initiated to determine the utility of helium embrittlement measurements in assessing helium mobility and distribution in RTNS-II irradiated materials. A major concern is the effect of fusion neutron induced helium generation centers on helium distribution and on mechanical behavior. It should be determined if altered helium distributions due to elements such as carbon can be detected and their effect on helium embrittlement ascertained.

Maximum fluences should be employed to achieve maximum helium contents.

3. The Effect of Hydrogen on Flow and Fracture

The preceeding section on Microstructure Evolution indicated that hydrogen will be generated at high rates in the fusion reactor first wall. Classically, hydrogen embrittlement is most often a problem in hcp and bcc alloys under service conditions leading to hydrogen charging at low temperatures (e.g., room temperature).[40]

There are no data on the effect of hydrogen on mechanical properties during or after elevated temperature irradiation. There are potential mechanisms for a significant effect (such as gas formation as noted before) and scoping studies are needed to assess the magnitude of the problem.

F. Damage in Superconductor Magnet Components

The superconductor magnet components, including superconductor, normal conductor, and insulator, are likely to be subjected to relatively low flux, high energy neutrons from various "leakage" channels; flux magnitudes are strongly design dependent. It is anticipated that maximum fluences will be on the order of 10^{19} to 10^{20} n/cm^2.

Moderate fluences (10^{18} n/cm^2) of high energy neutrons have been found to lower the critical current and the critical temperature of superconductors;(14,15) both effects result in a reduction in superconductor stability.

Studies of the resistivity change in the normal metal matrix (usually copper) have indicated an even larger effect of neutron irradiation. Increases of 60% in the resistivity of copper have been observed during low temperature 14 MeV neutron irradiation to 8×10^{16} n/cm^2.(13) This large increase in resistivity of the normal metal would have an adverse effect on the superconductor stability.

The strategy for studying high energy neutron damage in superconductor magnet components is dependent on the particular component. Whether organic insulators should be included depends on whether current fission reactor studies show that neutron damage is significant compared to gamma radiation damage. The situation regarding the normal (stabilizer) and superconducting components is somewhat unique in this Plan because 1) goal exposures are perhaps within reach in RTNS-II, and

2) higher damage rates at liquid helium temperatures will be attained in RTNS-II than in any existing low temperature neutron irradiation facility in the U.S. It is important to extend the present data base on potential materials for superconductor components to higher fluences and to assess how well data obtained in fission reactors can be applied to fusion reactor spectra. Data obtained in relatively short irradiations may indicate a strong need for much longer exposures. Such a need might best be met in FMIT, if a delay until after 1983 is not critical.

G. Surface Effects

High energy neutron sputtering studies on several materials have indicated low sputtering yields.[41] Current estimates are that surface sputtering due to high energy neutrons will be a small fraction of the total first wall sputtering rate.

The phenomenon is not completely understood, however. It may assume renewed significance if it is found to act synergistically with other processes such as changes in the structure and properties of the bulk material at high fluences, or those processes influencing the integrity of wall coatings.

IV. ASSIGNMENT OF PRIORITIES FOR RTNS-II EXPERIMENTS

The following priorities are based on four major considerations: The expected importance of the problem, the time available to seek a solution, the lack of approaches other than RTNS-II to address the problem, and the feasibility of obtaining meaningful results with RTNS-II.

The meanings of the priority symbols are given in relation to the DAFS milestones as follows:

Priority	Meaning
H	Highest impact of RTNS-II on achievement of DAFS milestone
M	RTNS-II data are necessary for milestone but less critical
D	RTNS-II data are desirable but not critical

A. Irradiation Environment Characterization

	Problem	Priority
1)	Description of the RTNS-II flux/fluence/spectrum	H
2)	Development of improved dosimetry techniques	M
3)	Accurate determination of helium and hydrogen generation rates	H
4)	Assessment of flux/fluence/spectrum characteristics of Be(d,n) and Li(d,n) facilites	M

Characterization of the RTNS-II was given high priority since the major purpose of the facility is to relate effects produced by 14 MeV neutrons to effects produced in other spectra (e.g., fission neutrons). This characterization includes dosimetry for each experiment as well as the initial description of the radiation characteristics.

High priority was given also to the determination of gas production rates. Helium content is often used as a damage characterization parameter and is expected to be important in other RTNS-II studies (microstructure evolution and mechanical properties).

B. Damage Production

	Problem	Priority
1)	Experimental determination of the primary damage state	H
2)	Development of experimental techniques for damage production studies	H

Damage production studies at RTNS-II were given high priority since the determination of the primary damage state will affect model development in the microstructure evolution and fundamental mechanical properties areas. The fluences attainable in RTNS-II are well-suited to damage production studies, where higher fluences would have little value.

The high priority for the development of new and improved techniques for damage production experiments is consistent with the importance of damage production and the need for better descriptions of the primary damage state.

C. Microstructure Evolution

	Problem	Priority
1)	The effect of the primary recoil spectrum	H
2)	The effect of transmutant helium	H

3)	The effect of transmutant hydrogen	D
4)	Relating high and low exposure microstructures	M

The effects of the primary recoil spectrum and transmutant helium were given highest priority because these are the two most important aspects of the fusion neutron energy spectrum. Furthermore, related studies indicate that, at the fluences attainable with RTNS-II, effects on the microstructure should be detectable.

The low priority given to hydrogen studies reflects the need to determine the feasibility of performing sensitive experiments at RTNS-II. The priority will also depend on the assessment of the severity of hydrogen embrittlement in an irradiation environment.

Developing the relationships between RTNS-II low exposure microstructures and subsequent high exposure microstructures is necessary for the full utilization of RTNS-II data. However, the role of RTNS-II in developing these relationships is not expected to be large, except in the area of providing seed microstructures for further growth in other facilities; hence, the assignment of the intermediate priority.

D. Fundamental Mechanical Properties

	Problem	Priority
1)	The effect of the primary recoil spectrum	H
2)	The effect of transmutant helium	H
3)	The effect of transmutant hydrogen	D

The priorities here parallel those for microstructure evolution.

Effects on the mechanical properties have already been observed in the important areas of high energy cascades and helium embrittlement. More data are needed in these areas to aid mechanical property model development. Feasibility studies are needed to assess the importance of hydrogen effects and to determine whether these effects are addressable by RTNS-II.

E. Damage in Superconductor Magnet Components

High energy neutron damage in superconductor magnet components is given the high priority of "H" because of the potential magnitude of the problem.

F. Surface Effects

High energy neutron sputtering yields are not required to meet any major milestone in the PMI Program Plan, so are given priority "D".

V. TASK DEFINITION

This section defines the tasks which should be performed at RTNS-II, what information should be gained from these tasks, and the time scale for obtaining this information. Task definitions for engineering studies are not included.

The milestone charts for the fundamental problems are given in relation to their impact on DAFS activities and major milestones. The task number prefixes relate to the three DAFS subtask groups as follows:

II.A Environmental Characterization
II.B Damage Production
II.C Damage Microstructure Evolution and Mechanical Behavior

Dashed time lines are used for DAFS subtasks; solid lines for RTNS-II activities.

The DAFS priorities are contained in the DAFS Program Plan. The RTNS-II impact designations are as follows:

H: Highest impact of RTNS-II on achievement of DAFS milestone
M: RTNS-II data are necessary for milestone but less critical
D: RTNS-II data are desirable but not critical

The number under Projected or Proposed Effort indicates specific entries in Appendix 2.

A time scale summary of the Task Definitions is given in Figure 2. The milestone designations are described in the respective Task Definitions.

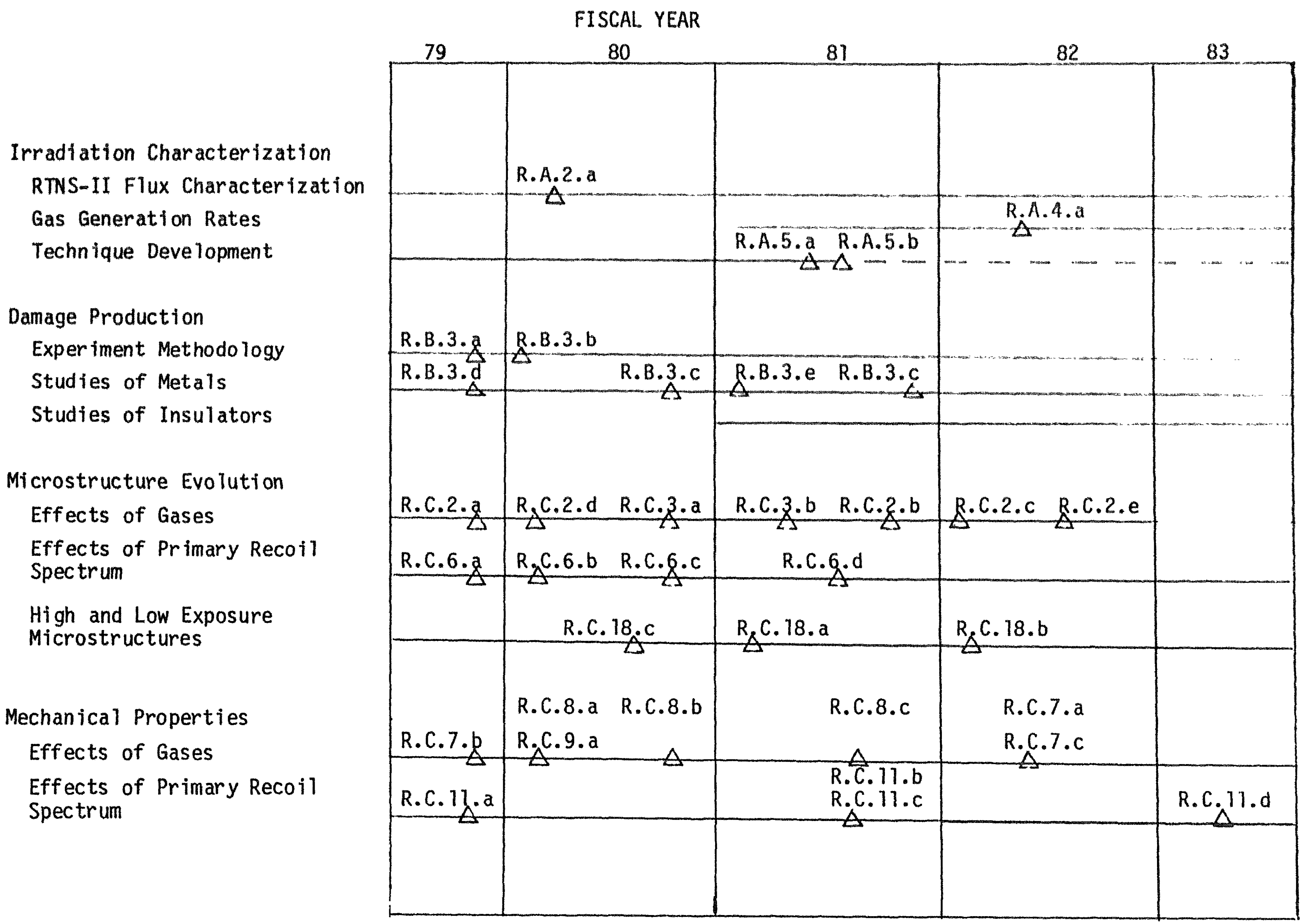


FIGURE 2. RTNS-II Task Schedule Summary. RTNS-II Milestones are defined in the Task Descriptions.

RTNS-II Task Number: R.A.2
DAFS Task Number: II.A.2
DAFS Task Title: High Energy Neutron Dosimetry
RTNS-II Input to Major Milestone: II-2,3,11,16

DAFS Objective: Establish the best practicable dosimetry for high energy neutron facilities.

RTNS-II Scope: Characterize RTNS-II irradiation characteristics

DAFS Subtask No.	DAFS Activity	RTNS-II Activity	DAFS Priority	RTNS-II Impact	Projected or Proposed Effort	FY 79	FY 80	FY 81	FY 82	FY 83
II. A.2.1	Flux-spectral definition in Be(d,n) field		H					c	d	
		R.A.2.1 Calibrate monitors		D	4,28					
II.A.2.2	Flux-spectral definition in RTNS-II		H				f			
		R.A.2.2 Mapping		H	4,28,32		a			
		R.A.2.3 Continuing dosimetry		H	4,20					

DAFS Milestones (o)

II.A.2.c Complete mapping

II.A.2.d Establish consistent cross section set

II.A.2.f Complete mapping

RTNS-II Milestones (Δ)

R.A.2.a Complete mapping

RTNS-II Task Number: R.A.4
DAFS Task Number: II.A.4
DAFS Task Title: Gas Generation Rates
RTNS-II Input to Major Milestone: II-1,9,12,14,15

DAFS Objective: To provide helium and hydrogen gas production data for irradiation correlations and for MFR applications.

RTNS-II Scope: Measurement of helium generation rates in selected elements and alloys. Hydrogen measurements to be made if warranted.

DAFS Subtask No.	DAFS Activity	RTNS-II Activity	DAFS Priority	RTNS-II Impact	Projected or Proposed Effort	FY 79	FY 80	FY 81	FY 82	FY 83
II. A.4.2	T(d,n)		H				o[b]		o[c]	
		R.A.4.1 He production		H	28,32				△[a]	
		R.A.4.2 H production		D	32					
II.A.4.3	Be(d,n)		H				o[d]		o[c]	
		R.A.4.3 Monitor calibration*		D	32					

DAFS Milestones (o)

II.A.4.b Complete RTNS-I

II.A.4.c Complete corroboration experiment in RTNS-II

II.A.4.d Complete close-in location measurements in available Be(d,n) source

II.A.4.3 Complete measurements with spectrum varied by changing location and/or changing deuteron energy

RTNS-II Milestones (△)

R.A.4.a Complete corroboration experiment

*No further irradiations required - included in subtask II.A.2.1.

DAFS Objective: To permit routine measurement of neutron fluence and energy spectra, and their spatial variations, for long-term irradiations in high energy sources.

RTNS-II Scope: Calibrate new techniques for characterization of RTNS-II and other facilities.

II-2

DAFS Subtask No.	DAFS Activity	RTNS-II Activity	DAFS Priority	RTNS-II Impact	Projected or Proposed Effort	FY 79–83
II.A.5.1	Helium accumulation monitor development		M			o a, o b (79); o c (80); o d (81); dashed through 83
		R.A.5.1 Test in T(d,n) field		M	28	79–81, Δ a
		R.A.5.2 Apply to RTNS-II		M	28	82–83
II.A.5.2	Track recorder development		D			o e (79); o f (80); o g (81); dashed through 83
		R.A.5.3 Scoping study in T(d,n) field.		D	32	79–81, Δ b
		R.A.5.4 Apply to RTNS-II		D	32	82–83
II.A.5.3	Develop and test new techniques as required		D			dashed 79–83
		R.A.5.5 Scoping studies in T (d,n) field		D	32	79–83

DAFS Milestones (o)

II.A.5.a Select reactions

II.A.5.b Test in T(d,n) field

II.A.5.c Test in Be(d,n) field

II.A.5.d Apply to RTNS-II

II.A.5.e Scoping studies in T(d,n) and Be(d,n) field

II.A.5.f Optimize procedures

II.A.5.g Apply to RTNS-II

RTNS-II Milestones (Δ)

R.A.5.a Assess application to RTNS-II

R.A.5.b Assess application to RTNS-II

RTNS-II Task Number: R.B.3
DAFS Task Number: II.B.3
DAFS Task Title: Experimental Characterization of the Primary Damage State
RTNS-II Input to Major Milestone: II-5,8,11,12

DAFS Objective: To characterize the primary damage state experimentally in circumstances of MFE interest.

RTNS-II Scope: Determine the primary damage state as a function of temperature for development and calibration of theoretical models.

DAFS Subtask No.	DAFS Activity	RTNS-II Activity	DAFS Priority	RTNS-II Impact	Projected or Proposed Effort	FY 79	FY 80	FY 81	FY 82	FY 83
II.B.3.1	Experiment methodology		D			o[a]				
		R.B.3.1 Assessment of detection techniques.		H	3,7,8,10, 11,17,18	Δ[a]				
		R.B.3.2 Separate microstructure evolution from primary damage state		H	12	Δ[b]				
II.B.3.2	Studies of metals		H						o[b]	
		R.B.3.3 Low-temperature studies		H	3,8,14,15,22		Δ[c]			
		R.B.3.4 Mid-temperature studies		H	7-10,13-15, 17,18,20,24		Δ[c]			
		R.B.3.5 High-temperature studies		H	6,7,10-12, 17,18	Δ[d]		Δ[c]		
		R.B.3.6 Scoping experiments comparing d-T and d-Be		D			Δ[e]			
II.B.3.3	Studies of insulators		H				o[c]			
		R.B.3.7 Perform experiments with guidance of theory		H	16,19					

DAFS Milestones (o)

II.B.3.a Complete assessment of techniques

II.B.3.b Complete fcc metals

II.B.3.c Define insulator requirements for MFR's

RTNS-II Milestones (Δ)

R.B.3.a Complete review of available detection techniques. Extend to experimental development as required.

R.B.3.b Determine effectiveness of pre-irradiation microstructure as a measurement of defect production.

R.B.3.c Determine nature of primary damage state in simple metal. Extend to more complex.

R.B.3.d Assess the feasibility of detecting the primary damage state at elevated temperatures.

R.B.3.e Compare d-T and d-Be irradiations. Extend if needed.

RTNS-II Task Number: R.C.2
DAFS Task Number: II.C.2
DAFS Task Title: Effects of Helium on Microstructure
RTNS-II Input to Major Milestone: II-6,8,9,12,13,14,15

DAFS Objective: Understand the behavior of helium in metals and its effect on microstructure evolution.

RTNS-II Scope: Determine the mobility and distribution of helium and helium effects on microstructure for conditions which may not be well simulated in fission neutron irradiations.

DAFS Subtask No.	DAFS Activity	RTNS-II Activity	DAFS Priority	RTNS-II Impact	Projected or Proposed Effort	FY 79	80	81	82	83
II.C.2.1	Mobility, distribution and bubble nucleation		H							
		R.C.2.1 Mobility and distribution.		H	1,4	Δa				
		R.C.2.2 Bubble re-solution		M	-			Δb		
II.C.2.2	Fast spectrum-mixed spectrum correlations for FeNiCr alloys		H			oa				
		R.C.2.3 Comparative irradiations in various facilities		H	14			Δc		
II.C.2.3	Charged particle-neutron correlations for refractory and reactive alloys		H							
		R.C.2.4 Comparative irradiations in various facilities		M	6	Δd			Δe	

DAFS Milestones (o)

II.C.2.a Assess implications of spectrum tailoring to vary He/dpa ratio.

RTNS-II Milestones (Δ)

R.C.2.a Assess the feasibility of detecting effects due to non-homogeneous helium generation. Extend to detailed characterization if feasible.

R.C.2.b Assess the ability of high energy cascades to disperse helium, and subsequent effects.

R.C.2.c Determine the importance of correct He/dpa ratio during early stages of irradiation.

R.C.2.d Assess the feasibility of detecting helium effects in non-nickel alloys.

R.C.2.e Determine the importance of simultaneous helium and neutron irradiation of non-nickel alloys.

RTNS-II Task Number: R.C.3
DAFS Task Number: II.C.3
DAFS Task Title: Effects of Hydrogen on Microstructure
RTNS-II Input to Major Milestone: II-7

DAFS Objective: Assess effects of hydrogen on microstructural evolution.

RTNS-II Scope: Determine the effect of hydrogen on microstructure evolution by comparing results from various facilities on dopec and undoped materials.

DAFS Subtask No.	DAFS Activity	RTNS-II Activity	DAFS Priority	RTNS-II Impact	Projected or Proposed Effort	FY 79	80	81	82	83
II.C.3.1	Mobility and distribution		H							
		R.C.3.1 Scope effect of hydrogen generation sites		D	-		△ a			
II.C.3.2	Irradiation of hydrogen doped alloys		*							
		R.C.3.2 Comparative irradiation in various facilities		M	-			△ b		

DAFS Milestones (o)

* see Task II.C.9

RTNS-II Milestones (△)

R.C.3.a Assess ability to detect non-homogeneous hydrogen distributions.

R.C.3.b Assess hydrogen doping as a simulation technique.

RTNS-II Task Number: R.C.6
DAFS Task Number: II.C.6
DAFS Task Title: Effects of Damage Rate and Cascade Structure on Microstructure
RTNS-II Input to Major Milestone: II-8,11,12,13,15

DAFS Objective: To understand effects on microstructural evolution of differences in damage rate and displacement damage structure.

RTNS-II Scope: Determine effect of high energy cascades on microstructure evolution by comparison of results from various facilities (fission, d-Be). Assess impact of material variables on these results.

DAFS Subtask No.	DAFS Activity	RTNS-II Activity	DAFS Priority	RTNS-II Impact	Projected or Proposed Effort	FY 79	FY 80	FY 81	FY 82	FY 83
II.C.6.3	Low energy-high energy neutron correlations		M					o c		
		R.C.6.1 Material scoping irradiations.		M	-	Δ a				
		R.C.6.2 Detection technique development		H	10,20	Δ b	Δ c			
		R.C.6.3 Comparative irradiations in various facilities		H	2,3,5,10,13, 19-21			Δ d		

DAFS Milestones (o)

II.C.6.c Incorporate data from RTNS-II

RTNS-II Milestones (Δ)

R.C.6.a Establish materials for further RTNS-II testing by their radiation damage sensitivity.
R.C.6.b Establish new detection techniques for further development.
R.C.6.c Correlate data obtained by new techniques with microstructure.
R.C.6.d Compare microstructure evolution in simple material with other irradiation facility results. Initiate extension to more complex materials.

RTNS-II Task Number: R.C.7
DAFS Task Number: II.C.7
DAFS Task Title: Effect of Helium and Displacements on Flow
RTNS-II Input to Major Milestone: II-6,8,9,12

DAFS Objective: Determine the effects of helium and displacements on flow.

RTNS-II Scope: The influence of helium and helium-induced microstructures on creep and tensile flow will be determined for representative materials (including non-nickel-bearing materials).

DAFS Subtask No.	DAFS Activity	RTNS-II Activity	DAFS Priority	RTNS-II Impact	Projected or Proposed Effort	FY 79	FY 80	FY 81	FY 82	FY 83
II.C.7.2	Post-irradiation testing		M						o[c]	
		R.C.7.1 Comparative irradiations on tensile properties		M	10				Δ[a]	
II.C.7.3	In-situ testing		H							
		R.C.7.2 Scoping studies on creep*		D	6	Δ[b]				
		R.C.7.3 Detailed creep studies (if feasible)		M	6				Δ[c]	

DAFS Milestones (o)

II.C.7.c Complete ORR-EBR-II(FFTF) creep test comparisons.

RTNS-II Milestones (Δ)

R.C.7.a Complete correlation of microstructure and flow to determine effect of helium and helium-induced microstructure on tensile properties.

R.C.7.b Determine feasibility of performing creep studies at RTNS-II.

R.C.7.c Determine the effect of helium and helium-induced microstructure on creep.

* Identical to scoping studies for activity R.C.11.1.

RTNS-II Task Number: R.C.8
DAFS Task Number: II.C.8
DAFS Task Title: Effects of Helium and Displacements on Fracture
RTNS-II Input to Major Milestone: II-6,13,14,15

DAFS Objective: Determine the effects of helium and displacements on fracture mechanisms and parameters.

RTNS-II Scope: Assess the effect of helium on embrittlement for cases that are not simulated in fission irradiations (e.g., grain boundary helium generation, and non-nickel-bearing alloys). Scoping studies will be performed to determine conditions for helium embrittlement and the utility of this information in studying helium mobility.

DAFS Subtask No.	DAFS Activity	RTNS-II Activity	DAFS Priority	RTNS-II Impact	Projected or Proposed Effort	FY 79	FY 80	FY 81	FY 82	FY 83
II.C.8.2	Post-irradiation testing		H			– –	– –	– –	- o a	- o b
		R.C.8.1 Comparative irradiations on ductility		M	10	△a	△b	△c		

DAFS Milestones (o)

II.C.8.a Calibrate grain boundary fracture models

II.C.8.b Complete evaluation of He/dpa effects in representative alloys

RTNS-II Milestones (△)

R.C.8.a Assess effectiveness of helium embrittlement studies in determining mobility and distribution of helium.

R.C.8.b Complete scoping studies on the effect of grain boundary helium generation on helium embrittlement.

R.C.8.c Assess helium embrittlement in non-nickel-bearing materials.

RTNS-II Task Number: R.C.9
DAFS Task Number: II.C.9
DAFS Task Title: Effects of Hydrogen on Fractur
RTNS-II Input to Major Milestone: II-7,15

DAFS Objective: Evaluate the potential significance of hydrogen effects in fusion materials.

RTNS-II Scope: Initial effort limited to a scoping study under conditions most likely to produce hydrogen embrittlement.

DAFS Subtask No.	DAFS Activity	RTNS-II Activity	DAFS Priority	RTNS-II Impact	Projected or Proposed Effort	FY 79	FY 80	FY 81	FY 82	FY 83
II.C.9.3	Experimental Program		?			---	o[c]			
		R.C.9.1 Room temperature scoping studies on bcc and hcp metals		D	-	—— △[a]				

DAFS Milestones (o)

II.C.9.c Complete formulation of experimental program (if warranted)

RTNS-II Milestones (△)

R.C.9.a Assess the effect of room temperature irradiation on hydrogen embrittlement of hcp or bcc metal.

RTNS-II Task Number: R.C.11
DAFS Task Number: II.C.11
DAFS Task Title: Effects of Cascades and Flux on Flow
RTNS-II Input to Major Milestone: II-11,12

DAFS Objective: Determine the effect of cascade structure and flux on irradiation creep rate and flow stress.

RTNS-II Scope: Determine the effect of the high energy neutron induced primary damage state and subsequent microstructure evolution on the creep rate and tensile properties.

DAFS Subtask No.	DAFS Activity	RTNS-II Activity	DAFS Priority	RTNS-II Impact	Projected or Proposed Effort	FY 79	FY 80	FY 81	FY 82	FY 83
II.C.11.4	High energy neutron irradiations		H			— —	— —	o d		
		R.C.11.1 Scoping studies on creep*		H	6	△ a				
		R.C.11.2 Detailed creep studies (if feasible)		H	6			△ b		
		R.C.11.3 Mid- and low-temperature tensile property studies		M	2,10			△ c		
		R.C.11.4 Elevated temperature tensile property studies		H	2,10					△ d

DAFS Milestones (o)

II.C.11.d Complete RTNS-II and d-Be irradiations

RTNS-II Milestones (△)

R.C.11.a Assess feasibility of performing creep tests at RTNS-II.

R.C.11.b Determine the effect of the primary damage state on creep in one material. Extend to microstructure evolution and other materials.

R.C.11.c Determine the effectiveness of mid- and low-temperature cascades in impeding dislocation motion.

R.C.11.d Determine the effect of high energy cascade induced microstructure on tensile properties.

* Identical to scoping studies for activity R.C.7.2

RTNS-II Task Number: R.C.18
DAFS Task Number: II.C.18
DAFS Task Title: Relating Low and High Exposure Microstructures
RTNS-II Input to Major Milestone: II-6,9,11,12,14,15,16

DAFS Objective: To understand the nucleation of microstructures and the influence of the nucleation microstructure on subsequent growth.

RTNS-II Scope: Relatively low exposure irradiations would be used to study nucleation phenomena as influenced by material and irradiation parameters. Preconditioned microstructures would be produced for subsequent irradiation in other facilities.

DAFS Subtask No.	DAFS Activity	RTNS-II Activity	DAFS Priority	RTNS-II Impact	Projected or Proposed Effort	FY 79	80	81	82	83
II.C.18.1	Nucleation experiments		H			– –	o a	– –	– –	– –
		R.C.18.1 Comparative irradiations in various facilities		H	1,3,20	——	——	△ a	△ b	——
II.C.18.2	Growth of preconditioned materials		H			– –	o b	– –	– –	o c
		R.C.18.2 Precondition materials		H	5	——	△ c	——	——	——

DAFS Milestones (o)

II.C.18.a Compare fission and 14 MeV neutron data (RTNS-II)

II.C.18.b Complete pre-irradiations

II.C.18.c Complete characterization of re-irradiated specimens

RTNS-II Milestones (△)

R.C.18.a Initial assessment of the effect of irradiation variables on nucleation microstructure.

R.C.18.b Initial assessment of the effect of material variables on nucleation microstructure.

R.C.18.c Complete preconditioning of materials for scoping growth studies. To be continued if scoping studies warrant.

VI. PROGRAM IMPLEMENTATION

A. OFE Funded Programs

The experiments projected for the RTNS-II fall primarily within the scope of the DAFS Task Group. Therefore, should the load on the facility warrant it, this group will review proposed experimental programs for technical content and relevancy. Priorities will be recommended to the Materials and Radiation Effects Branch. The Branch will, of course, make the final judgment regarding support for the experiment and its priority.

B. Other Programs

Requests from non-OFE programs for RTNS-II irradiations will be handled by the Materials and Radiation Effects Branch on a case by case basis. It is expected that many of these will complement DAFS experiments, hence may be reviewed by the DAFS Task Group.

VII. REFERENCES

1. Program Plan, prepared by the ETM Task Group on Damage Analysis and Fundamental Studies, 1978.

2. H. Farrar IV, D. W. Kneff, A. Britten and R. R. Heinrich, "Fluence Mapping of RTNS-I by Helium Accumulation and Foil Activation Methods," in Proc. Symp. on Neutron Cross-Sections from 10 to 40 MeV, M. R. Bhat and S. Pearlstein, eds; pp 175-184, National Nuclear Data Center, Brookhaven National Laboratory, Upton, NY, BNL-NCS-50681, July 1977.

3. J. C. Davis, "RTNS-II Technical Development Plan," Lawrence Livermore Laboratory Report, UCID-17146, January, 1976.

4. H. Farrar and D. W. Kneff, "Helium Generation Cross-Section Results from the First AI RTNS-I Irradiation," Damage Analysis and Fundamental Studies Technical Progress Report for October, 1977 to March, 1978, p. 58.

5. T. A. Gabriel, B. L. Bishop and F. W. Wiffen, "Calculated Irradiation Response of Materials Using a Fusion-Reactor First-Wall Neutron Spectrum," Submitted for publication in Nuclear Technology.

6. W. N. McElroy and H. Farrar IV, "Helium Production in Stainless Steel and Its Constituents as Related to LMFBR Development Programs," in Radiation-Induced Voids in Metals, USAEC, 1972, p. 187.

7. L. R. Greenwood, R. R. Heinrich, R. J. Kennerley, and R. Medrzychowski, "Development and Testing of Neutron Dosimetry Techniques for Accelerator Based Irradiation Facilities," To be submitted for publication in Nuclear Technology.

8. J. R. Beeler, Jr., Phys. Rev. 150, 470 (1966).

9. M. J. Robinson and I. M. Torrens, Phys. Rev. 9, 5008 (1974).

10. D. G. Doran and J. O. Schiffgens, "Cascade Annealing--An Overview," Proc. of the Workshop on Correlation of Neutron and Charged Particle Damage, CONF-760673, 1976, p. 3.

11. J. B. Roberto, C. E. Klabunde, J. M. Williams and R. R. Coltman, Jr., "Damage Production by High-Energy d-Be Neutrons in Cu, Nb and Pt at 4.2°K," Appl. Phys. Lett. 30, 509 (1977).

12. M. W. Guinan and C. E. Violet, "Initial Damage Rates in Nb, V and Mo from 30 MeV D-Be Neutrons," in Proc. Symp. on Neutron Cross-Sections from 10 to 40 MeV, M. R. Bhat and S. Pearlstein, eds; pp 361, National Nuclear Data Center, Brookhaven National Laboratory, Upton, NY, BNL-NCS-50681, July 1977.

13. J. B. Roberto, C. E. Klabunde, J. R. Williams and R. R. Coltman, Jr., "Isochronal Recovery of High-Energy d-Be Neutron Damage in Cu, Nb, and Pt from 8 - 400°K," J. Nucl. Mat. 73, 97 (1978).

14. R. M. Scanlon, "Low Temperature Irradiations of Niobium-Titanium with 14-MeV Neutrons," UCRL-79418, May 1977.

15. C. L. Snead, Jr., D. M. Parkin, M. W. Guinan and R. A. Van Konynenburg, "Determination of the Damage-Energy Cross Section of 14 MeV Neutrons from Critical-Property Changes in Irradiated Nb_3Sn," in Proc. of the 2nd Topical Meeting on the Tech. of Controlled Nuclear Fusion VI, 1977, p. 229.

16. J. B. Roberto, J. Narayan and M. J. Saltmarsh, "15 MeV Neutron Damage in Cu and Nb," in Proc. of Internat. Conf. on Radiation Effects and Tritium Technology for Fusion Reactors, 1976, ERDA/CONF 750989, p. II-159.

17. J. Roberto and M. J. Robinson, "The Energy Dependence of Neutron Damage in Cu and Nb," J. Nucl. Mater. 61, 149 (1976).

18. J. Narayan and S. M. Ohr, "The Characteristics of 15 MeV and Fission Neutron Damage in Niobium," J. Nucl. Mater. 63, 454 (1976).

19. J. Narayan, "The Nature of High-Energy Neutron Damage in Copper and Gold," ORNL Solid State Division Annual Progress Report, Period Ending April 30, 1977, ORNL-5328, p. 91.

20. J. B. Mitchell, R. A. Van Konynenburg, C. J. Echer and D. M. Parkin, "DT Fusion Neutron Radiation Strengthening of Copper and Niobium," in Proc. of the Intern. Conf. on Radiation Effects and Tritium Technology for Fusion Reactors, 1976, CONF-750989, p. II-172.

21. J. B. Mitchell, "Exploratory Experiments Comparing Damage Effects of High-Energy Neutrons and Fission-Reactor Neutrons in Metals," LLL Report, UCRL-52388, 1978.

22. J. L. Brimhall, L. A. Charlot and H. E. Kissenger, "14 MeV Neutron Damage in Molybdenum," Rad. Effects 28, 115 (1976).

23. R. J. Borg and G. J. Dienes, "Short Range Order in Au-Fe Radiation-Enhanced Diffusion and the Effectiveness of 14 MeV Neutrons," J. Appl. Physics 46, 99 (1975).

24. A. C. Damask, R. Van Konynenburg, R. J. Borg and G. J. Dienes, "Comparison of the Free Vacancy Production in α-Brass by Fission Reactor Neutrons and 14.8 MeV Neutrons," Rad. Effects 29, 237 (1976).

25. J. Narayan and B. C. Larson, "D-T Fusion Neutron and Nickel Ion Damage in 316 Stainless Steel," Trans. Am. Nucl. Soc. 26, 191 (1977).

26. J. B. Mitchell, C. M. Logan and C. J. Echer, "Comparison of 16 MeV Proton, 14 MeV Neutron and Fission Neutron Damage in Copper," J. Nucl. Mater. 48, 139 (1973).

27. R. L. Lyles and K. L. Merkle, "14 MeV Neutron Damage in Ag and Au," in Proc. of the Intern. Conf. on Radiation Effects and Tritium Technology for Fusion Reactors, 1976, CONF-750989, p. I-191.

28. J. B. Mitchell, R. A. Van Konynenburg, M. W. Guinan and C. J. Echer, "Some Electron Microscopy Observations of 14 MeV Neutron Damage in Niobium," Phil. Mag. 31, 919 (1975).

29. J. E. Harbottle and S. M. Dickerson, "Neutron Induced Voids in Nickel: The Low Dose Dependence at 400°C" J. Nucl. Mater. 44, 313 (1972).

30. J. O. Stiegler and E. E. Bloom, "Void Formation in Irradiated Nickel 270," Rad. Effects 8, 33 (1971).

31. B. Mastel and J. L. Brimhall, "Voids Produced in High Purity Nickel by Neutron Irradiation," J. Nucl. Mater. 28, 115 (1968).

32. E. E. Bloom, "An Investigation of Fast Neutron Radiation Damage in an Austenitic Stainless Steel," USAEC Report ORNL-4580, 1970.

33. R. W. Powell, "Void Formation in Nickel by a Low-Temperature Irradiation, Post-Irradiation Anneal Technique," Ph.D. Thesis, Massachusetts Institute of Technology, 1974.

34. G. L. Kulcinski, D. G. Doran and M. A. Abdou, "Comparison of Displacement and Gas Production Rates in Current Fission and Future Fusion Reactors," Properties of Reactor Structural Alloys After Neutron or Particle Irradiation, ASTM STP 570, 1975, p. 329.

35. D. K. Matlock and W. D. Nix, J. Nucl. Mater. 56, 145 (1975).

36. E. A. Kenik, Transactions of ANS Winter Meeting 27, 1977, p. 275.

37. A. L. Bement, Jr., Advances in Nuclear Science and Technology 7, 1 (1973).

38. A. D. Brailsford and R. Bullough, "The Termination of Void Growth in Irradiated Materials," Proceedings of the Intern. Conf. on Defects and Defect Clusters in B.C.C. Metals and Their Alloys, 1973, p. 493.

39. R. L. Fish and J. J. Holmes, "Tensile Properties of Annealed Type 316 Stainless Steel After EBR-II Irradiation," J. Nucl. Mater. 46, 113 (1973).

40. G. E. Dieter, Jr., Mechanical Metallurgy, McGraw-Hill Book Company, Inc., 1961, p. 388.

41. R. Behrisch, O. K. Harling, M. J. Thomas, R. L. Brodzinski, L. H. Jenkins, G. J. Smith, J. F. Wendelken, M. J. Saltmarsh, M. Kaminsky, S. K. Das, C. M. Logan, R. Meisenheimer, J. E. Robinson, M. Shimotomai and D. A. Thompson, "Sputtering of Niobium by Energetic Neutrons and Protons: A Round-Robin Experiment," J. Appl. Physics 48, 3914 (1977).

APPENDIX 1

RTNS-II Description

RTNS-II

Expected Operating Characteristics

Full Power	-	March 1979
Neutron Spectrum	-	14 MeV from T(d,n) reaction
Peak Source Strength	-	4×10^{13} n/sec
Maximum Flux	-	1×10^{13} n/(cm^2-sec)
Target Lifetime	-	100 hours
Deuteron energy	-	400keV
Deuteron current	-	150 ma
Deuteron beam diameter	-	1 cm
Target rotation rate	-	5000 rpm

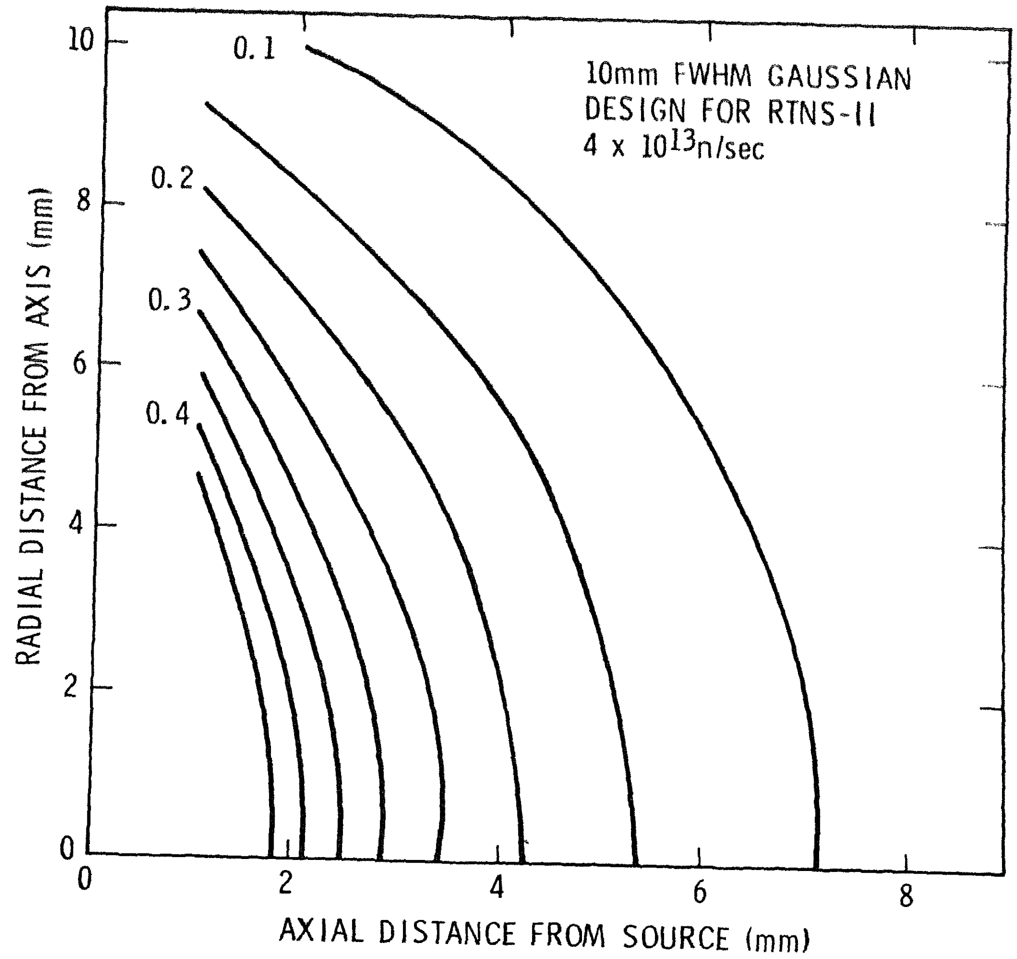


Figure A1. Flux Plot Near Source. Average flux (in n/cm^2-s) over the lifetime of the target is plotted as a fraction of peak source strength (4×10^{13} n/s). Three mm axial distance from source is the estimated closest approach for experiments.

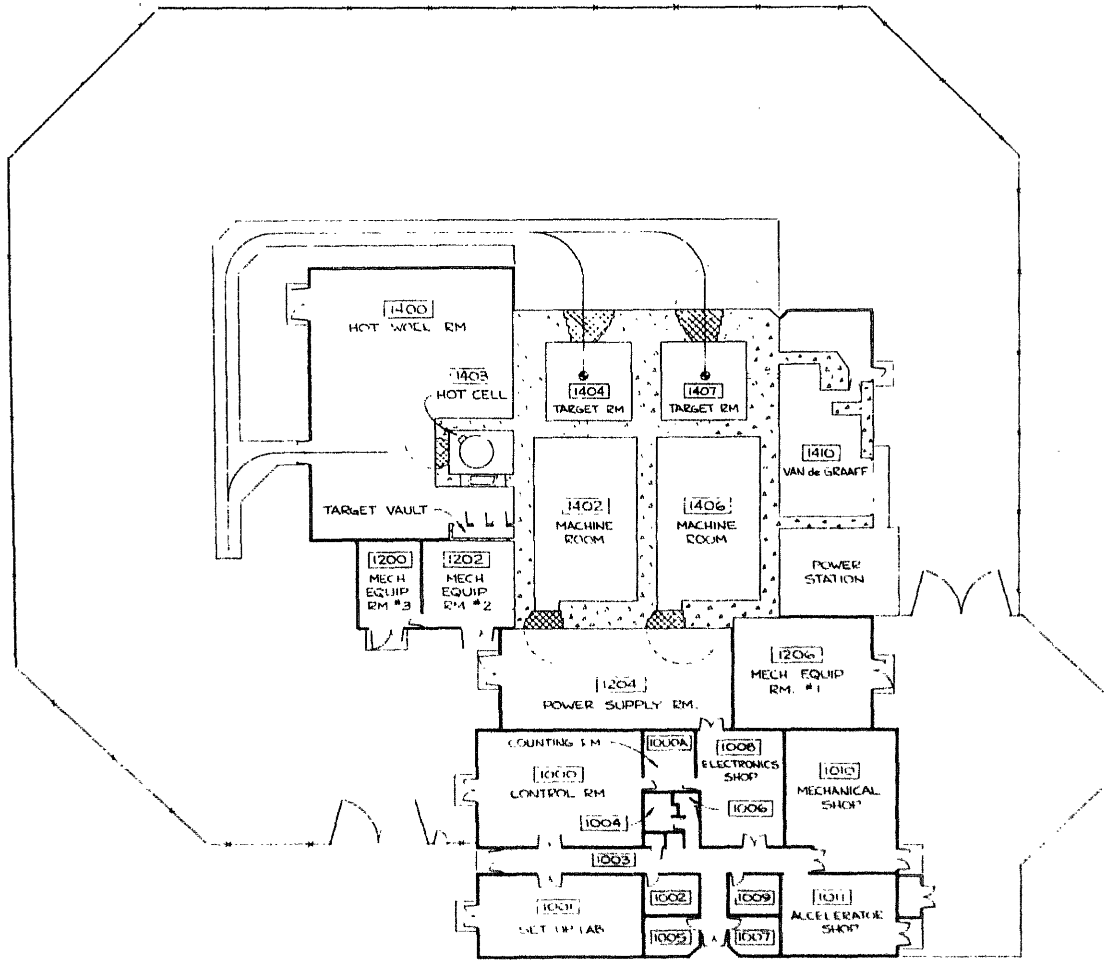


FIGURE A2. Floor Plan of RTNS-II Facility.

APPENDIX 2

Summary of Projected or Proposed RTNS-II Experiments

SUMMARY OF PROJECTED OR PROPOSED RTNS-II EXPERIMENTS

Principal Investigator	Organization*	Experiment Description	Experiment Objective	Desired Fluence, n/cm^2	Temperature	Planned Date, FY	DAFS Subtask No.
1. J.A. Spitznagel	W-R&D	Helium pre-doped specimens for atom probe, ion channeling and anelastic relaxation measurements	Kinetics and microstructural sensitivity of helium/point defect clustering	2×10^{17} - 1×10^{19}	300-700°C	81-83	II.C.2.1, II.C.2.2., II.C.18.1
2. R.H. Jones	PNL	TEM and tensile tests of representative path A, B and C alloys	1) Comparison of energetic neutrons and light ions on microstructure evolution 2) Relationships between microstructure and mechanical properties	1×10^{17} - 5×10^{18}	20°C, 200-800°C	79-83	II.C.6.3, II.C.11.4
3. M.W. Guinan	LLL	Resistivity increase and annealing of pure metals with a range of atomic weight and crystal structure.	Total defect production, including clusters, relative to fission spectra.	10^{17}	-270°	79-80	II.B.3.2
		Resistivity of short range ordered alloys	Free defect production	10^{17}	20°C-elevated	79-80	II.B.3.1, II.B.3.2
		Resistivity of fully ordered alloys	Replacement production through resistivity increase	10^{18}	-270°C-20°C	79-80	II.B.3.1, II.B.3.2
		TEM of pure metals with a range of atomic weight	Void nucleation relative to fission spectra	10^{18}-5×10^{19}	elevated	79-83	II.C.6.3, II.C.18.1
		Resistivity and magnetic measurements of alloys	Phase stability relative to fission spectra	10^{18}-5×10^{19}	elevated	79-83	II.C.1.1, II.C.6.3 II.C.18.1
4. L.R. Greenwood	ANL	Mapping studies of neutron fields and integral testing of activation data	Characterization of neutron field	10^{16}-10^{18}	20°C	79-83	II.A.2.1, II.A.2.2
5. G.L. Kulcinski	U. Wisc.	Ion bombardment of pure metals following high energy neutron preconditioning	Assess the effect of high energy neutron preconditioning on the high fluence microstructure	10^{19}-10^{20}	20°C-700°C	80-83	II.C.6.3, II.C.18.2
6. F.V. Nolfi	ANL	Irradiation creep-stress relaxation measurements	Determine defect production rates	-	Elevated	81	II.B.3.2, II.C.2.3, II.C.7.3, II.C.11.4
7. J.A. Sprague	NRL	Superlattice darkfield TEM of ordered precipitates	Determine cascade size	-	-	-	II.B.3.1, II.B.3.2

Principal Investigator	Organization*	Experiment Description	Experiment Objective	Desired Fluence, n/cm^2	Temperature	Planned Date, FY	DAFS Subtask No.
8. M. Kirk	ANL	TEM and resistivity of ordered alloys	Concentration and size of cascade clusters and number of free defects	10^{17}-10^{18}	-270°C-20°C	79-81	II.B.3.1, II.B.3.2
9. K. Merkle	ANL	TEM and resistivity of pure metals including observation of surface crater formation	Concentration and size of cascade clusters and number of free defects-quantitative comparison with cascade theory. Comparison of crater formation with theory.	10^{16}-10^{18}	20°C	79-80	II.B.3.2
10. G.R. Odette	UCSB	Destructive, non-destructive and microstructural tests	Comparison with models to ascertain defect production parameters and selected physical, mechanical and microstructural properties	10^{17}-10^{19}	20°C-elevated	79-82	II.B.3.1, II.B.3.2, II.C.6.3, II.C.8.2 II.C.11.4
11. P.R. Okamoto	ANL	Near surface solute segregation	Free defect production rate	-	Elevated	-	II.B.3.1, II.B.3.2
12. H. Wiedersich	ANL	High energy neutron induced loop growth rates in pre-nucleated material	Free defect production rate and dislocation bias	10^{18}-10^{20}	Elevated	-	II.B.3.1, II.B.3.2
13. W.J. Gray	PNL	Irradiate graphite	Defect characteristics in graphite	10^{17} max.	20°C	79-80	II.B.3.2, II.C.6.3
14. J.B. Roberto/ R.R. Coltman	ORNL	Resistivity, TEM, and X-ray diffuse scattering on pure metals. Recovery following low temperature irradiation	1) Cascade size, defect density and influence of subthreshold events. 2) Relationship between target mass, damage energy and defect distribution.	10^{17}-10^{19}	-270°C-20°C	-	II.B.3.2
		Measure helium production rates and influence on swelling	Effect of helium on microstructure evolution	10^{18}-10^{19}	Elevated	-	II.C.2.1, II.C.2.2
		X-ray, resistivity and annealing following high energy neutron preconditioning and short charged particle irradiation	Growth of defect aggregates	-	20°C-Elevated	-	

Principal Investigator	Organization*	Experiment Description	Experiment Objective	Desired Fluence, n/cm^2	Temperature	Planned Date, FY	DAFS Subtask No.
15. S. Sekula	ORNL	Flux-pinning effects in annealed and cold-worked superconducting alloys.	Pinning strength of cascades and defect clusters		-270°C-20°C	-	II.B.3.2
		Degradation of T_c with fluence in A15 compounds	Test damage energy correlation	-	-270°C-20°C	-	II.B.3.2
		Degradation of stability of commercial composite superconducting materials.	Delineate engineering limits	-	-270°C	-	
16. Y. Chen	ORNL	Spectroscopic measurements of irradiated MgO	Determine anion vacancy and divacancy concentrations	10^{18}-10^{20}	20°C	-	II.B.3.3
17. J. Narayan	ORNL	X-ray and TEM of Cu, Nb and pure 316	Concentration, size and type of clusters	10^{17}-10^{19}	20°C-500°C	80	II.B.3.2
18. D. Parkin	LASL	Dislocation damping and Zener relaxation measurements made in-cell.	Free interstitial production cross-section	10^{18} max.	20°C-Elevated	80-81	II.B.3.1, II.B.3.2
19. F.W. Clinard	LASL	TEM and optical absorption plus density, thermal diffusivity, microhardness and fracture toughness measurements of irradiated ceramics. Isochronal anneals.	Nature of point defects and aggregated defects in ceramics. Survey of changes in physical properties.	1×10^{19}	20°C	79	II.B.3.3, II.C.6.3
20. C.L. Snead	BNL	Incremental irradiations of superconductors	Superconductor property correlations between fission and high energy neutrons	10^{18}-10^{19}	20°C	79-83	II.B.3.2
		Positron sample irradiation	Determine void and bubble nucleation and growth with positron annihilation technique	10^{19}	20°C-Elevated	79-83	II.C.6.3, II.C.18.1
21. K.H. Westmacott	LBL	High energy neutron irradiations and 1.5 MeV HVEM irradiations	Establish validity, limitations and advantages of simulation techniques to predict high fluence behavior	10^{18}-10^{20}	20°C-Elevated	80	II.C.6.3
22. R.M. Scanlon	LLL	Superconductor specimen irradiation without warm-up	Determine the effects of high energy neutrons on the superconducting properties	10^{19}	-270°C	80-81	II.B.3.2

Principal Investigator	Organization*	Experiment Description	Experiment Objective	Desired Fluence, n/cm^2	Temperature	Planned Date, FY	DAFS Subtask No.
23. R.R. Coltman, Jr.	ORNL	Mechanical and electrical properties of organic and composite insulators after high energy neutron irradiation and γ irradiation	Significance of high energy neutrons relative to fission neutrons and gamma radiation	10^{18}	-270°C	80	-
24. O. Harling/ M.T. Thomas	MIT/PNL	Neutron sputtering yield experiment on atomically clean surfaces	Direct comparison with theoretical sputtering yields	5×10^{17}-5×10^{18}	20°C	79-80	II.B.3.2
25. M. Kaminsky	ANL	Neutron sputtering yield experiments on EPR and demo-materials	Particle release and near surface alteration	1×10^{18}-5×10^{18}	20°C	80	-
		Sputtering yield experiments with simultaneous high energy neutron and helium bombardment	Particle release and near surface alteration	1×10^{18}-5×10^{18}	20°C	80	-
26. E.A. Henry	LLL	14 MeV neutron irradiation of ^{235}U followed by fast chemistry	14 MeV neutron induced fission to study nuclei in the "valley" of the fission distribution, yield as a function of neutron energy and fission nuclei with a threshold for neutron induced fission	-	20°C	79-82	
		14 MeV neutron induced reactions	Production and study of heavy, neutron rich nuclei	-	20°C	79-82	
27. P.K. Hopke	U. Ill.	Irradiation of various materials including biological tissues, coal and coal ash with multielement comparator standards followed by rapid gamma ray spectroscopy	Development of a trace multielement analytical technique for analyses of many difficult to analyze elements	10^{14}-10^{17}	20°C	80	
28. H. Farrar, IV	AI	Elemental and alloy irradiations followed by mass spectroscopic helium analysis	Determine helium generation rates. Measure neutron flux with HAFM's and development of technique	-	20°C	-	II.A.2.1, II.A.2.2, II.A.4.2, II.A.5.2

Principal Investigator	Organization*	Experiment Description	Experiment Objective	Desired Fluence, n/cm^2	Temperature	Planned Date, FY	DAFS Subtask No.
29. D.G. Doran	HEDL	High resolution TEM; pre-irradiation microstructure control; mechanical properties	Technique development for damage detection and separation of simultaneous processes	10^{17}-10^{18}	20°C-600°C	79-80	II.B.3.1, II.C.6.3
		TEM microstructure characterization; hot microhardness	Determine damage production and microstructure evolution for comparison with models and fission data. Compare microstructure with mechanical properties.	10^{17}-10^{19}	-270°C-600°C	78-83	II.B.3.2, II.C.2.1, II.C.2.2, II.C.2.3, II.C.6.3, II.C.7.2, II.C.8.2, II.C.11.4, II.C.18.1
30. C.M. Logan	LLL	Routine dosimetry	Characterization of neutron exposure	-	-	78-83	II.A.2.2
		Development of deuteron beam monitoring system	Assurance of reproducible neutron fields	-	-	78	II.A.2.2
31. W.L. Primak	ANL	Irradiation of window materials for TFTR	Development of TFTR windows	-	20°C	78-79	-
32. R. Gold/ J.H. Roberts	HEDL	Irradiation of various pure metals and SSTR's	Determine PKA spectra and neutron sputtering rates with advanced SSTR techniques	10^{18}	20°C	80-82	II.B.3.1
		Irradiation of passive dosimetry capsules	Develop and evaluate SSTR, emulsion, radiometric and HAFM dosimetry for high energy neutron spectra	10^{17}-10^{19}	20°C	79-83	II.A.2.2, II.A.5.2, II.A.7.1
		Angular distribution measurements of alpha and proton reaction products from various elements using SSTR techniques	Cost effective measurement of helium and hydrogen generation cross-sections	10^{18}	20°C	79-83	II.A.4.2, II.A.4.3, II.A.4.4
		Exposure of high energy neutron detectors	Test and evaluation of active prototype neutron detectors for FMIT application	-	20°C	80-81	II.A.2.4, II.A.5.3, II.A.7

*	AI	Atomics International
	ANL	Argonne National Laboratory
	BNL	Brookhaven National Laboratory
	HEDL	Hanford Engineering Development Laboratory
	LASL	Los Alamos Scientific Laboratory
	LBL	Lawrence Berkeley Laboratory
	LLL	Lawrence Livermore Laboratory
	MIT	Massachusetts Institute of Technology
	NRL	Naval Research Laboratory
	ORNL	Oak Ridge National Laboratory
	PNL	Pacific Northwest Laboratory (Battelle)
	UCSB	University of California at Santa Barbara
	U. Ill.	University of Illinois at Urbana - Champaign
	U. Wisc.	University of Wisconsin at Madison
	W-R&D	Westinghouse Research Laboratories

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